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Looking Ahead
in
Aviation Lighting

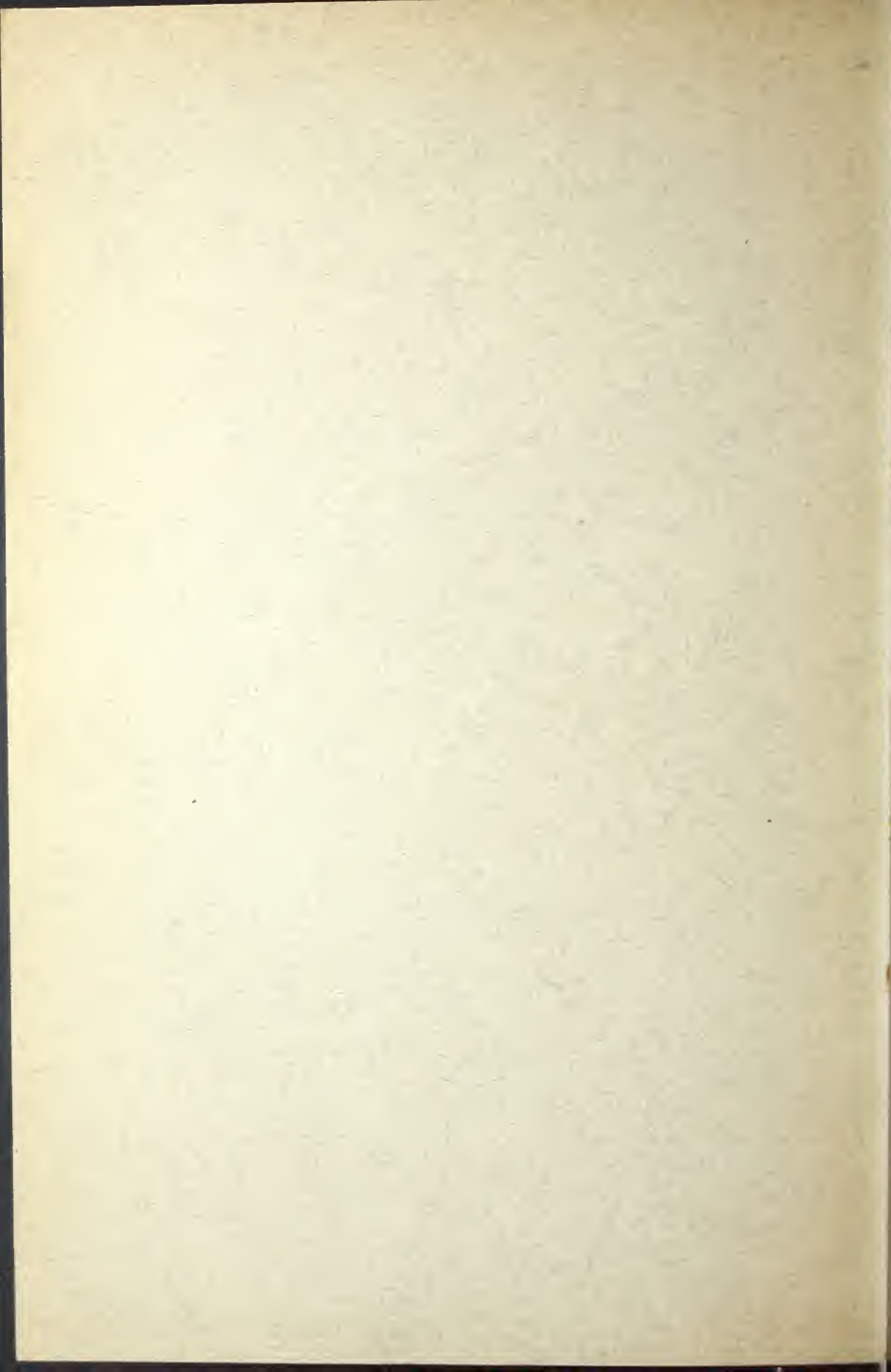
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LOOKING AHEAD
in
AVIATION LIGHTING



ENGINEERING DEPARTMENT
National Lamp Works of General Electric Co.
NELA PARK : CLEVELAND, OHIO

FOREWORD

It is the purpose of this bulletin to summarize the part light is already playing in the service of aviation and to call attention to requirements of airport lighting that are likely to be encountered in the future. While some of the suggestions may appear too ambitious for the present, they are presented with the thought of meeting future requirements with a minimum of expense over a reasonable period of time.

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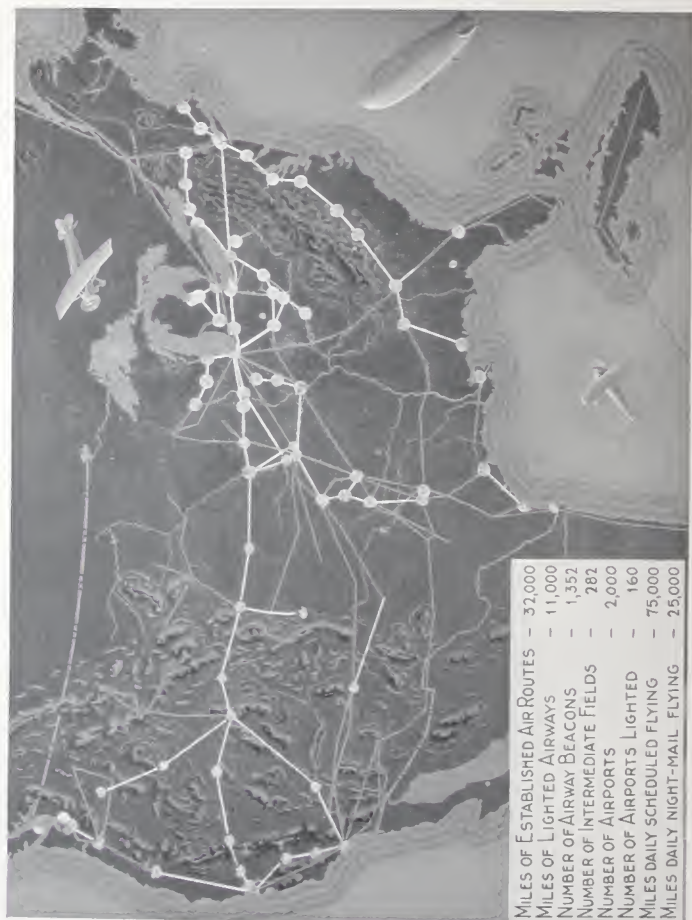


FIG. 1—LIGHT WILL PUT YOUR AIRPORT ON THE NIGHT MAP OF AMERICA



The aviation industry is moving ahead with unprecedented rapidity. Today 8,000 airplanes are in service, 4,300 of which were built last year. In 1929, 10,000 planes will be manufactured. Within the next few years, it is estimated that 100,000 planes will be in service, demanding airway and airport facilities. This is roughly equivalent to the number of automobiles now in use in the entire nation of Belgium or Sweden. Even those in the most favorable situation as regards a broad perspective of the industry are hesitant to predict what the trend of engineering development will be or what requirements will have to be met more than a year or two in the future as far as airport planning is concerned.

Suffice to say that the airport has outgrown the status of a "wind-sock" in a pasture field and is gradually assuming the dignity of an indispensable terminal in a growing, expanding transportation system. Already expenditures for airport development aggregate well on to a half billion dollars and another half billion expenditure is involved in plans under way. This huge expenditure is made up of sums ranging from a few thousand dollars in smaller localities up to one, two, and as high as seven million dollars for complete airport terminal developments in the more important centers.

Unstinted tribute must be given those in the aviation industry who are pushing ahead in the face of major developmental problems to which not even highly paid experts can vouchsafe the real answer. The marvelous growth of the electrical industry has been due to the same pioneering spirit. While mistakes have been made and

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revolutionary developments have been the principal cause of equipment depreciation, the industry has always been characterized by that attitude of mind expressed by one of the outstanding electrical leaders that *his greatest asset was his junkpile*. It is probable that the aviation industry will have to meet and adapt itself to even more rapidly changing conditions than did the electrical industry. Greatest success will come to those whose plans are flexible enough to take the turns on the winding, unlit road ahead.

Good Lighting is Cheap Insurance

The expediency of aviation in meeting public needs depends upon night flying as a matter of course. Lighting therefore becomes of prime importance to the success of the industry.

The general requirements of lighting for night flying are fairly well understood and developments in lamps and equipments to meet these requirements have been made; however, it cannot be considered that the solution of the problem is at all standardized. Present aircraft and airport developments, serving present needs are, like the automobiles and highways of a quarter century ago, essentially pioneers for greater developments to come.

One need not be over-optimistic to sense great commercial developments of aviation and as these things come about, the lighting must keep pace. New standards will be demanded for safety, convenience, and general sense of security and well-being which the public quickly learns to expect. The future will likely see the use of light increased many fold over the threshold values used today.

The aviation industry in its lighting provisions can well profit from experiences of other industries in their attitude toward light and lighting economics. While an engineer in his recommendations must balance practical idealism with administrative and financial conditions as they actually exist, not a small part of his responsibility is to guard against mere expediences which are likely soon to render installations obsolete; he must perforce project himself into the future far enough in his plans to provide for orderly development, extensions and additions as required with as little depreciation as possible on the initial investment.

The present practice of airport lighting has grown out of the necessity of providing some sort of illumination largely for the

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service of air mail. The municipalities have been so suddenly projected in the business of airport administration with the inevitable requirement of bond issues for land, grading, sewers, buildings, etc., that the element of cost has been a considerable factor in limiting desirable lighting practice. The result has been to provide the barest necessities as far as lighting is concerned, and these apparently have been adequate for the relatively few plane movements we have today, coupled with the fact that most of the pilots doing night flying are experienced and extremely resourceful.

It is significant that lighting is one of the three major features on which an airport obtains a rating from the United States Department of Commerce. The standards set up in the Airport Rating Regulations are in the nature of minimum requirements and as such they are more properly to be worked *from* rather than *to*. While minimum standards are necessary they oftentimes react to limit progress. Particularly is this true in such branches of engineering where engineer specialists alone can visualize and evaluate the efficacy of printed specifications, and where competitive bids and awards are usually based on minimum standards.

Those planning airport lighting facilities should anticipate the requirements, not in terms of minimum values but in terms of safety, general utility and expediency of traffic operations, such as any large, active industrial or commercial enterprise might comprehend. The cost of the best system of lighting is small compared to its service in extending the use of the airport throughout 24 hours a day. The advertising value of light should not be overlooked. To inspire confidence and build up patronage for air travel no factor is more important than adequate airport lighting.

A single serious accident—aside from the danger to human life—due to inadequate lighting might involve more expense than the entire cost of the best lighting facilities.

If we dare consider aerial transportation in the light of a potentially great industry and think of an airport in terms of a large industrial establishment whose floor space consists not only of enclosed hangars for housing equipment, but also of open landing fields as a part of the production and service area essential and peculiar to this new industry, we can gain some idea of the possible future use of light as an investment for the safety, convenience and general acceptance of night flying service.

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An industrial plant having, say, 3,000,000 square feet of floor space would have, conservatively, 3,000 kilowatts of lighting installed. Large theatres employ from 50 to 500 kilowatts for lighting only the stage. Large electrical advertising displays use 100 to 300 kilowatts. Present lighted airports, employing a lighting load of the order of 25 to 40 kilowatts show distinctly a meager use of light considering relative usefulness and importance of the application.

The filming of the movie "Broadway" employed over 4 million watts of electrical energy for lighting the set. This, roughly, was more wattage than was being used in the lighting of all the 10,000 miles of lighted airways and in lighting all the airports in the United States at the time of release of the film early this year. More light for a single movie production than was provided for the safety of air transportation over 40,000 miles of daily flying on established air routes!

Use of Light in Aviation Service

Lighting for aviation may be divided into four general classifications as follows:

1. Airway Lighting
2. Airport Lighting
3. Air Marking and Signaling
4. Aircraft Lighting

Lamps and equipments and methods for the use of light for each of these applications have been developed and are in service in a limited way. New developments will follow to meet new requirements which are certain to come as the volume of air traffic increases.

On Page 9 is a brief description of the lighting provisions for the system of lighted airways now in operation. This system of airways maintained by the Federal Government already links population centers comprising eighty million people. However, the value of this airway system to a city or community on or near the

Summary of Provisions for the Lighted Airways

An airway is considered as a strip 5 miles wide leading from one airport to another. The establishment and administration of civil airways is in the charge of the Director of Aeronautics, Department of Commerce, who is responsible for beacons, intermediate landing fields, signals, radio, and general navigation facilities for the safe operation of aircraft over such routes. To date, 1352 beacons and 282 intermediate landing fields are in operation over 11,000 miles of lighted airways.

Airway Beacons

Located approximately every 10 miles along airway. Beacons consist of 24-inch, 1000-watt, 2,000,000-candlepower projectors revolving at 6 r.p.m. Projectors are mounted on towers and are equipped with automatic lamp changers. Visible for 25 to 40 miles in clear weather.

Two 18-inch, 500-watt "on course" projectors are mounted on the platform below beacon and point forward and backward on the airway course. These are fitted with red cover glasses and deliver 17,000 candlepower, with 10 degree vertical and 15 degree horizontal spread. Course lights flash beacon number in Morse Code.

Intermediate Landing Fields

About every 30 miles along airway; identified by yellow course lights. In addition to beacon the lighting comprises boundary lights, approach lights, obstruction lights, and illuminated wind cone. All kept burning from sunset to dawn. No field floodlighting is provided because of limited power available at the majority of fields; landings must therefore be accomplished by aid of airplane landing lights or parachute flares.



Fig. 2—Typical Airway Beacon



Fig. 3—Intermediate Landing Fields are located every 30 miles along established air routes. Although only in the experimental stage, the feasibility of intermediate field floodlighting has been demonstrated by the installation of switch control apparatus responsive to audible signals from a wind driven siren on the airplane.

Minimum Lighting Facilities Required for an Airport to Obtain an "A" Rating

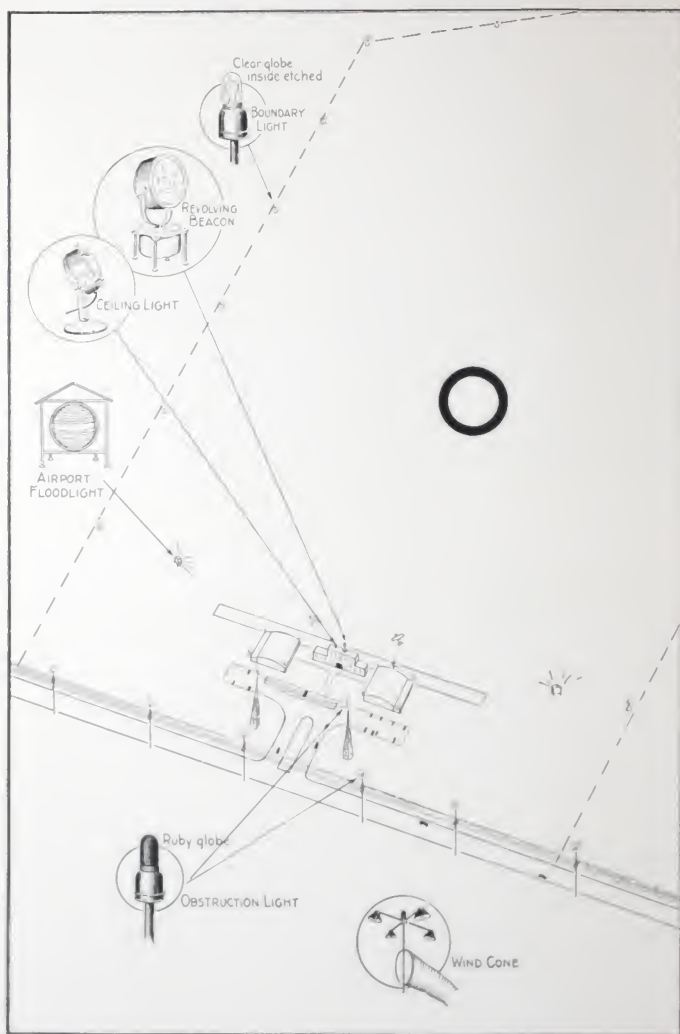
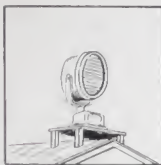


Fig. 4—Typical airport layout showing lighting equipment and its location; on on Page 11 is a brief abstract of the minimum lighting provisions required by the Department of Commerce Rating Regulations

Minimum Lighting Facilities Required for an Airport to Obtain an "A" Rating



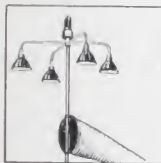
Airport Beacon

Minimum candlepower not less than 100,000 for long range, and in no case less than 15,000 candlepower. Rotating or flashing with flashes not less than one-tenth second duration or luminous period not less than 10 per cent. Light distribution such as to be visible all around horizon and to the zenith, or nearly so, for altitudes of 500 to 2000 feet; distinctiveness for identification; automatic lamp changers or auxiliary units for reliability.



Boundary and Obstruction Lights

Either 600-lumen series or 25-watt multiple lamps in clear weather proof globes on standards 30 inches above ground and spaced not more than 300 feet apart to outline boundaries or landing strips. Multiple circuits limited to 5 per cent voltage drop. Green substituted for white to show points of best approach, and red globes to show hazardous approaches, using 1000-lumen series or 50-watt multiple lamps. All obstructions in vicinity must have red lights at highest points of obstruction.



Wind Cone and Hangar Lighting

Illuminated wind-direction indicator to be visible from 1000 feet in all directions if externally floodlighted. Wind cones internally lighted require not less than 200-watt lamp in suitable reflector.

Exterior surface of each hangar to be floodlighted to 2½ foot-candles with surface reflection factor at least 50 per cent.

Ceiling Light

A 12-inch, 250-watt incandescent lamp searchlight 7 degree maximum beam spread to be installed for ceiling height measurements.

Field Floodlighting

One or more units to provide an even distribution of illumination without shadow areas and of sufficient illuminating power as to make ground details visible from an altitude of 30 feet. The minimum vertical plane illumination over the usable portion of landing area shall not be less than 0.15 foot-candles. System to be controlled from convenient point and sufficiently flexible to permit landing under all conditions of wind direction without the necessity of landing directly toward the light source.



Units shall be mounted as low as possible consistent with contour of ground, and shall project a beam of narrow vertical divergence with sharp cut-off at top so as not to produce glare. When more than one unit is used, each shall be independent from the other in operation. In case of a single light source floodlighting unit, an automatic lamp changer shall be provided. In lieu of a lamp changer an auxiliary unit may be used which will give not less than 0.035 foot-candles over the usable portion of the field.

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established air routes will depend largely on their alertness to provide and develop adequate airport facilities.

While each municipality must work out its own destiny as far as airport development is concerned, the Department of Commerce has set up an effective clearing house for statistical data and for helpful cooperation on all phases of airport construction and operation. Their Airport Rating Regulations define the basic requirements for airports and a system of rating designations have been established whereby airports obtain an accredited rating based on three major factors, namely, (1) General Equipment and Facilities; (2) Size of Landing Area; (3) Night Lighting Equipment. The ratings are designated in order by a letter, a figure and another letter, as A1A, which is the highest rating given.

On Page 10 is shown an airport layout in which the various lighting equipments are illustrated and on Page 11 is a brief of the Department of Commerce requirements for an airport to obtain an "A" rating on night lighting facilities. It should be emphasized again that requirements for rating are minimum values required today and, as discussed later, are not necessarily the best recommendation from the standpoint of using light to the fullest advantage for safety, for traffic control, for convenience and flexibility, or for general advertising value and general acceptance of night flying as a practical enterprise.

The Lighting Problem

The layman is likely to be carried away from the true conception of lighting results by the highly spectacular nature of great shafts of light piercing the sky, or be misled by the staggering figures of millions of beam candlepower in which modern types of projection equipment are rated.

Candlepower alone, though rating the strength of a light source in a certain direction indicating in a way its piercing power or, in other words, how far it may be seen from a distance, gives little information of the volume of light that may be available for illuminating purposes. For example, an ordinary automobile headlight bulb emitting only about 200 lumens of light in suitable reflecting equipment, may produce a beam of 100,000 candlepower while a 1000-watt lamp emitting 20,000 lumens in another type of

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equipment may also produce only 100,000 candlepower maximum though the latter will illuminate one hundred times as great an area.

The process of molding light from a lamp into a piercing shaft is not unlike the fashioning of a ball of metal into a slender rod. Rough gauge presses might shape the ball into an oblong chunk, it might be hammered further into a slender rod; if greater length were desired, this rod might be rolled through more accurate gauges, into wire. This wire might be further lengthened by drawing through a series of accurately ground diamond dies until, finally, our original ball of metal, only a few inches in diameter, is reduced to a thin wire several miles in length.

A light source such as a bare MAZDA lamp is simply a ball of light, emitting rays in all directions. Reflectors and lenses are the tools by which this sphere of light is drawn out into a piercing shaft, a spreading fan, or any other light pattern that is best suited to the particular application. Unlike molding metal into patterns when we attempt to control light we lose a part of our original quantity at each step in the process of refinement—the actual loss—or conversely the resultant useful light obtained depends upon the type of equipment employed, the degree of control necessary, and the skill of the designer in the choice and manipulation of his light-moulding tools.

The amount of light from any light source can be readily measured and all MAZDA lamps are rated in terms of the amount of light emitted. Where large areas are to be lighted, the ordinary procedure is first to ascertain the area (in square feet) to be lighted and to decide the degree of illumination required and from these two factors determine the total volume of light that must be provided. Equipments should then be designed which will deliver this volume of light efficiently; the choice of equipment will depend upon the actual locations of the equipment with respect to the area to be lighted, the number of units to be employed, and the projection distances.

The MAZDA Lamp in Aviation Service

The MAZDA lamp, because of its simplicity of operation, reliability in service, its natural color quality as well as its adaptability to color media, is best adapted to all phases of airport lighting. Its operation requires no auxiliary regulating mechanisms or

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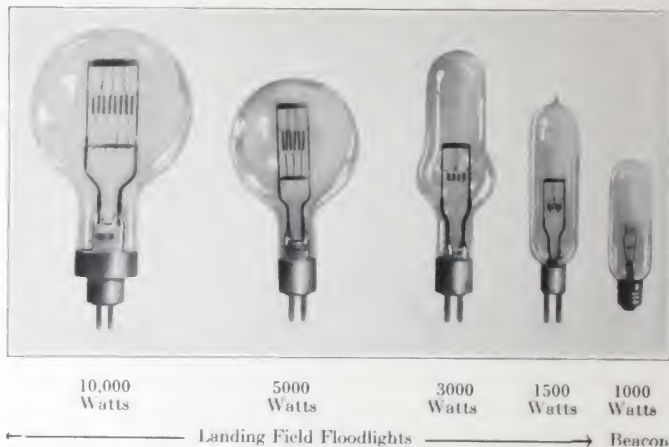


Fig. 5—MAZDA lamps specially designed for Aviation Service

attention and can therefore be readily controlled from any desired point. Furthermore, the wide range of sizes and the adaptability to use in all manner of focusing equipment, permit accurate control of the light and the provision for any amount of light, properly distributed, and for the least cost of operation.

Several special types of MAZDA lamps have recently been developed to meet the needs of aviation service. These lamps, shown in Fig. 5 are of high wattage of special design and filament construction best adapted to accurate light control in reflecting equipment. While a more complete summary of lamp data is included in the appendix, it is interesting here to note the impetus the needs of aviation have given to lamp research and improvement. Heretofore there always appeared inherent difficulties in high wattage lamps causing early failures and low efficiency of such lamps due to excessive bulb blackening. These difficulties have recently been overcome by the use of free tungsten particles which can be swished around and the bulb blackening removed at intervals by this process. This and other more recent processes of treating the filament have paved the way for new high marks for all time in the practical operating efficiencies of incandescent lamps.

AIRPORT BEACONS

Airport beacons are the main guideposts in the expanding network of silver trails rapidly linking important centers in a vast aerial highway system. They serve, essentially, as destination markers to guide the pilot from afar and to herald the proximity of a landing area. As such they should stand out distinctly as airport beacons, identified from among the air lane beacons which are placed at ten-mile intervals on all lighted air routes.

The installation and maintenance of a suitable beacon is one of the first requisites in the lighting requirements of an airport. Airport beacons as well as all other lighting facilities of an airport are a part of the administration of each individual airport and as far as installation and maintenance are concerned are independent of the system of air lanes and navigation aids provided by the Department of Commerce for established air routes.

The ordinary aerial beacon consists of a powerful rotating searchlight with its single slender pencil of light which describes a saucer-shaped sweep of light as the beacon rotates. A typical beacon unit is shown in Fig. 6.



Fig. 6

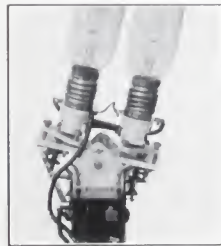


Fig. 7

Fig. 6 shows typical 24-inch beacon with parabolic mirror using 1000-watt, 115-volt, T-20 bulb Mazda lamp. Equipped with automatic lamp changer, shown in Fig. 7, which automatically moves a spare lamp into focal position in case of failure of other lamp. Metal drum housing below lamp contains a motor and gear mechanism for rotating beacon, the speed controlled as desired. The standard rate of rotation is 6 r. p. m. Develops 2,000,000 beam candlepower with 5 degree beam spread.

Requirements for Airport Beacons

The effectiveness of an airport beacon depends upon several factors:

1. High candlepower for long range visibility;
2. Visibility from all normal flying heights;
3. Suitable duration of flash period;
4. Positive identification.

In order to effect the greatest visibility range, the beacon must develop a beam of extremely high candlepower. The relation between candlepower of a light source and visibility distance is dependent largely on atmospheric conditions. With airway beacons 10 miles apart, the ideal airway beacon is one of sufficient candlepower to be visible 10 miles under the worst atmospheric conditions. The airport beacon which is more important than any individual beacon on an airway should have even a greater range. Unfortunately, the transmission of light through air falls off very rapidly due to clouds, smoke, or fog, even to the point of opacity. This is due to the fact that the water and dust particles in the atmosphere scatter the light rays and destroy the beam characteristics of the projected light.

At the present time it is impractical to build a beacon to concentrate a beam of this extreme candlepower, and the alternative seems to be to a closer spacing of beacons of the present type if light is to be effective through heavy fog. At present the radio beacon seems to offer the most likely solution of the bad weather problem. Radio beacons, however, do not have the simplicity nor offer the same feeling of reliability as a line of visible lights. Regardless of the developments in radio beacon navigation it is felt that light beacons of some sort will always be demanded as friendly guidesposts of the air to reassure the air traveler in quite the manner as highway markers at frequent intervals cheer the motorist along his way.

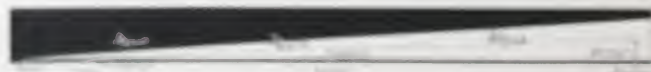


Fig. 8—A beacon with only a slender pencil of light is ineffective at close range at normal flying height.

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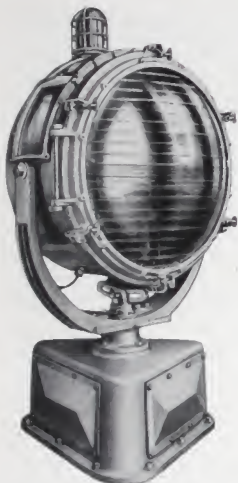


Fig. 9—Airway and Airport Beacon

On the other hand if the beam is confined to a 3 to 5 degree spread in an endeavor to obtain maximum beam candlepower, the effectiveness of the beacon is reduced because a plane at normal or abnormal flying height will benefit only for the short time it may be in the main beam. It will be seen from Fig. 8 that the revolving beacon creates a beam track, the center of which is 1895 feet high at 10 miles and only 234 feet high at one mile, consequently the beam is limited in the locations of pick-up. Approaching the beacon, a plane traveling at uniform height soon passes out of the main beam into a dimly lighted region.

The latest U. S. Department of Commerce design specifications for airway beacons recognize this point in providing for a 25 degree fan of light above the main beam. In addition four cylindrical lenses are provided in the upper part of the housing, which emit some light so that the beacon is visible from any position overhead. Such a beacon is shown in Fig. 9. Any redistribution of light from a projector is accompanied by a sacrifice of beam candlepower of the main beam. It is true that the candlepower values for the upper angles approaching zenith need be but a fraction of the candlepower needed for the angles near the horizontal for equal visibility since the pilot observer will be correspondingly near the beacon. However, under adverse weather conditions higher candlepower values in the upper zones would be of distinct advantage.

There is the third factor which enters into the problem in connection with the present aviation beacons, that is, the question of flash period. The standard beacons have a beam spread of about 5 degrees and rotate 6 times a minute. This does not allow the light to fall on the pilot's eye for a sufficiently long period of time to permit the eye to reach its maximum response, that is, the impression on the eye is the product of the intensity of the light

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and the length of time the retina is exposed to it, up to the saturation point. If the present rotating beacon is stopped in its rotation with the beam trained directly toward an observer the beacon appears to become much larger and more brilliant. A greater beam spread would therefore produce a more effective beacon.

Longer flash period can be obtained in two ways, either by slowing up the speed of rotation or by spreading out the beam. The former is not desirable because less than 6 flashes per minute allows a pilot to travel too far between flashes. Great increase in spread of the beam means loss in beam candlepower. There is probably a point where the gain due to longer flash period obtained by greater beam spread would just offset the loss on maximum beam candlepower. This is one of the things which should be determined. Perhaps it may prove desirable to spread the beam somewhat and maintain present maximum candlepower, by using a somewhat different shaped filament so as to increase the spread in the horizontal direction or by using somewhat higher wattage lamps than the present standard, or by using several lamps and several projector equipments each of which is designed to add its light distribution for the best effect of the beacon as a whole.

The latter possibility has led to the consideration of a multi-light projector as shown in Fig. 11. It will be noted that two long range projectors are provided with their beams offset both vertically and laterally which increases the effective beam spread to 10 degrees each without the loss of candlepower. In addition to the long range narrow angle projectors, auxiliary projectors are provided of such beam characteristics as to create a vertical fan of light of



Fig. 10—Experimental dome-type beacon. Lamp and reflector unit rotate inside of enclosed glass dome. In addition to the long range high candlepower beam, this design permits considerable light otherwise lost in the housing, to become effective in the upper zones.

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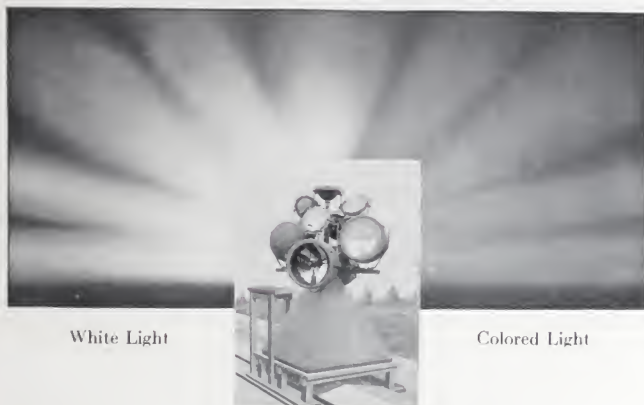


Fig. 11—Experimental Beacon Used at the Cleveland Municipal Airport.

In addition to the several projectors so designed and aimed to produce a solid sweep of light through the upper 180 degree hemisphere, a duplicate set of projectors has been provided. These are fitted with red cover glasses so that as the beacon rotates, it alternately sweeps a path of red and then white light through the sky. The lamping of both sets of projectors is identical and since the red color screen has a transmission factor of about 30 per cent the maximum candlepower of the red projector is of the order of 600,000 candlepower (30 per cent of 2,000,000).

relatively high candlepower visible from any location in the upper horizon. Wider beam spreads with resultant reduced beam candlepower are satisfactory for the auxiliary projectors since the plane within range of their beams is relatively nearer to the beacon.

Colored Light Beacons

The use of colored beacons, particularly red, was first advocated because of the general impression concerning the ability of red rays to penetrate fog. It has long been known that the atmosphere is somewhat selective in the transmission of radiant energy of different wave lengths. Fairly definite values for transmission of radiant energy from the sun through clear atmosphere have been established for the various wave lengths, indicating a relatively higher transmission of the longer wave lengths. At the earth's surface under varying conditions of water vapor and dust or smoke particles data are not so complete. It has been observed that there is a

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marked difference in fogs, thus, in different localities different characteristics are exhibited as to the particular wave lengths that penetrate best.

Various red light beacons with both neon and incandescent sources have been tested for visibility by the Bureau of Standards and reported as follows:

"The tests show that there is no real difference in the fog-penetrating quality of light from the two sources. In beacons of moderate candlepower any advantages due to the distinctive color of a neon lamp may be obtained more conveniently and simply and more reliably by means of an incandescent filament lamp equipped with a suitable color screen."

"Comparison of two incandescent filament lamps of equal energy input, one of which was provided with a red color screen having a transmission coefficient approximately 30 per cent, showed that the white light could invariably be seen a greater distance through fog than the colored light."

It seems logical that high source candlepower is of more importance in transmission than any advantage of slightly higher transmission of a particular wave length. Since the incandescent lamp source lends itself to ready use in reflecting and focusing equipment it is the most effective, reliable, and economical source of high beam candlepower producing either white light or light of any other color for identification purposes.

The higher visibility of white light beacons (maximum candlepower) during bad weather deserves their being retained, although it is recommended that they be supplemented by colored projectors for positive identification and pick-up. The sight on map of a city is nothing more than a myriad of lights—street lights, lighted building signs, and flashes from automobile headlights, particularly where the streets and thoroughfares are rolling. Because of this, white light beacons do not call attention to themselves and are not picked up as quickly as are colored beacons which contrast with the lights of the city. It is felt therefore that the airport beacon should provide both clear and colored beacons of high candlepower—the first for the greatest visibility under adverse conditions, the latter for quick and positive identification of the airport location. Where two or more airports are in close proximity each airport might be assigned a particular identifying color.

BOUNDARY LIGHTING AND OTHER LIGHTING ADJUNCTS

These indispensable aids designate to the pilot, after the beacon has guided him to the airport, the exact limits of the landing area or best points of landing approach, and point out all obstructions which form hazards at low flying altitude. Since these applications present no unusual problem of electrical installation or of light control, only the principal features will be discussed.

Boundary Lights

Boundary lights serve to define the limits of the flying field area. These are placed at regular intervals around the boundaries showing the immediate layout of the field. On a few fields where cinder or hard-surface runways have been established, boundary lights in combination with runway floodlights have been installed to outline the runway boundaries. This system presents immediately to the pilot a picture pattern of the runway layout. However, where any considerable amount of traffic movement is expected at an airport in the future, it is likely that intersecting runways will be abandoned and as funds for development are made available all fields will be so graded and surfaced that the entire area within the outside boundaries will be available for plane movement. For this reason the outlining of runways seems a temporary expedient.



Fig. 12—Typical boundary light installations: (A) Prismatic globe and conical skirt; (B) Plain globe and stem; (C) White glass globe with reflector-type guard, and conical base.

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While white light boundary markers are customary in the United States, there is considerable merit in the practice of certain European countries to use red or amber globes. Boundary lights define the limits between hazardous and non-hazardous landing areas and therefore have somewhat the same significance as other obstruction lights and can well be of a color which signifies *caution* or *danger*. It is extremely difficult oftentimes to differentiate between white boundary lights and street lights in the neighborhood, whereas a standard colored globe such as amber would make them easily recognizable.

The unit which was first developed for this application consists of a vapor-proof globe and fitting mounted on a 2 to 3-foot stem of galvanized conduit, as shown in Fig. 12b. The globe may be either a small enclosing globe with a moisture-proof fitter or preferably a prismatic enclosing globe designed especially for this service. The latter globe has the advantage of controlling the light and increasing the candlepower in the upward direction. This increases the pick-up distance and proves of considerable advantage under conditions of poor visibility.

Because of the slender stem, boundary lights are oftentimes inconspicuous in the daytime when the light or surroundings are such as to merge with the background. For that reason, it is recommended that each boundary light be surrounded by a 3-foot circle of whitewashed crushed rock or slag. Later types of boundary light as used on emergency landing fields and airports are shown in Fig. 12A and C. The conical sheet metal skirt is painted yellow and is very conspicuous. This skirt also acts as a support for the lighting standard which is connected to the electric circuit with a separable plug connector. This makes the unit less dangerous as an obstacle in case of a collision with it.

Early practice called for the spacing of boundary lights from 200 to 300 feet. It has been found, however, that spacings of this order are too great to give the best results. This is particularly true of airports located adjacent to streets or highways paralleling the boundaries of the field and because of the closer spacing of street lighting units, it may be difficult to identify the smaller more widely spaced boundary light sources. Furthermore, a pilot passing over one corner of the field may have difficulty recognizing this as a corner; this is particularly true under adverse weather conditions when the units are spaced at considerable distances.

If boundary lighting units are spaced from 75 to 125 feet apart a pilot flying over any corner of the field will be able to see enough of the boundary lights to orient his position.

It is recommended, therefore, that provision be made in the wire and circuit capacity for the installation of boundary lights on a 75 to 125 foot spacing, even though for present purposes a wider spacing may be suitable.

The installation of boundaries is simplified by pickaway cable which can be laid in plow furrows and covered over with dirt to a depth of 18 inches or more. Either series or multiple distribution may be used, the actual choice depending on the most economical system with regard to electric service available and to the particular arrangement of distribution centers and switching. In general the multiple system requires a higher investment in copper, although this is offset to some extent by the lower cost of multiple lamps. The series system imposes additional requirements as regards line capacity, constant current transformers, and safety with interground between the high voltage circuit and the lamp to avoid the danger of exposed high voltage in case of collapse or other damage to the lamp support. The multiple system introduces the problem of excessive voltage drop when the boundary lighting system is considered by itself. For that reason the series system has been installed more generally than the multiple system. However, if we look into the future as regards the best arrangement of field flood-lighting units as well as other facilities which will require electric service at various points about the field, it is possible that the multiple system will eventually prove the more economical.



Fig. 13—Laying "Pickaway" Cable in a plowed furrow for boundary light installation.



Fig. 14—This "Viable Flow" method the ground, bore the cable and connect up for use immediately.

Approach and Obstruction Lights

To indicate the most favorable points of approach in landing, one or more units in the boundary lighting system may be equipped with green colored globes. Such indications are particularly helpful on irregularly shaped fields or on fields where special grading or surfacing have provided smooth runways.

To indicate all obstacles on the field itself or any obstructions in the vicinity of an airport, a red light has been designated as a standard marker. These should be placed on all buildings, trees, water tanks, towers, smoke stacks, pole lines, fences, etc., in such a position as to be visible from all directions. In the case of very tall towers near the airport, a red light should mark every 30 feet of vertical height. Warning lights for major obstructions such as radio towers, water tanks, tall buildings, and the like, may be installed on flashing circuits but the flashing mechanism must be such as not to interfere with radio reception in the vicinity.

Both the green approach lights and the red obstruction markers should preferably be lamped with 100-watts or the equivalent to compensate for the absorption of light by the colored globes.



Fig. 15—View showing Airport Beacon, Wind-Cone Unit, and Obstruction Lights on a Hangar

LOOKING AHEAD IN AVIATION LIGHTING



Fig. 16—Typical Wind-Cone Unit



Fig. 17—Wind-tee atop the Observation and Control Tower

Lighted Wind-Indicators

The wind cone, which serves the pilot in indicating the direction and approximate velocity of the wind, will have the same appearance at night as in the daytime if lighted by a general flood of light from above. This has led to the design of a special wind-cone unit consisting of a fixture with four reflectors mounted on 2-foot brackets. The unit uses four 150-watt or four 200-watt lamps; in addition, a 60-watt lamp in a red color hood at the top of the standard serves as an obstruction marker. A typical wind cone-unit is shown in Fig. 16. The best location of the wind cone is at a point away from brightly lighted surroundings in order to stand out from the other light sources. Internally lighted wind cones, with a 200-watt lamp and reflector in the mouth, are also used to some extent.

The "wind-tee" shown in Fig. 17 is a very effective wind direction indicator but gives no indication of wind velocity. At night it is distinguished in outline by green incandescent lamps on neon tubes. A supplementary circuit of red is provided for emergency as a signal to pilots not to land.

Ceiling Projector

Probably one of the most important aids to aerial navigation is the interchange between airports of information on existing weather conditions, particularly with regard to height of clouds, commonly referred to in aviation parlance as the "ceiling" height. Low hanging clouds and fog are serious hazards causing danger of collision with trees, stacks, and other high obstacles as the plane flies low seeking bearings on the field location.

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Fig. 18—Ceiling
Projector

By the use of a 500-watt, narrow beam projector, directed upward at a definite angle, and by noting where the beam is scattered by the cloud bank, the height of the clouds can be approximated by simple triangulation. Direct readings of ceiling height are obtained by use of a ceiling height indicator. This device consists of a simple quadrant and pointer set in the same plane as the projected beam and a definite distance from the projector. By sighting along the pointer the point where the beam strikes the clouds, a direct reading of ceiling height is indicated.

Exterior Hangar Lighting

Illumination of the vertical sides of hangars or other buildings adjacent to the landing area serves the very useful purpose of creating normal perspective by which a pilot can judge his height above the ground when gliding in to make a landing. Two systems early suggested themselves, both of which have been satisfactorily used. Angle reflectors with 200-watt lamps spaced 8 to 10 feet apart, mounted on 6 foot conduit stems at the eaves will serve to illuminate the sides of the building in the same fashion as a lighted posterboard. This scheme meets the requirements but is open to the criticism from the standpoint of appearance. As one commentator expressed it, the trend is distinctly away from the "glorified tin garage" type of hangar, giving way to buildings of more permanent aspect and of some architectural character. It is true that the modern airport is rapidly taking its place as a legitimate civic enterprise calling for full expression of civic planning.

This suggests the installation of standard floodlighting equipment in place of angle reflectors to floodlight one or several principal airport buildings. Such floodlighting will serve the double purpose of providing a definite aid to the pilot and further serving to beautify the airport building in the same pleasing and attractive manner that so many commercial buildings are being floodlighted. Floodlights may be mounted on poles a short distance from the wall or on the roofs of adjacent buildings. The wattage required will depend on the type and the number of floodlights used. A floodlight equipped with horizontal spreading lens produces a beam pattern best adapted to the ordinary single story hangar building.

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Fig. 19—Night appearance of floodlighted hangar buildings

This modified beam produces uniform coverage with fewer units. Six to ten foot-candles on the vertical surfaces should be provided.

As a substitute for floodlighting either by angle reflectors or floodlights, the idea of lighted hangar windows would seem to offer an equally effective scheme. Either special lighting on the interior or if the regular interior lighting is of high standard, the light transmitted through the windows would by itself give the incoming pilots a good perspective of height. This necessitates keeping the interior lights burning but here again they will be doing double duty. This scheme is equally effective as that of special exterior floodlighting since the transmitted light in most cases gives a greater surface brightness than that obtained by the usual standard of floodlighting. This, in addition to the illumination provided by the landing field floodlights where buildings or trees surround the airport, should be adequate for vertical perspective. Illustrations of two methods of exterior hangar lighting are shown in Figs. 19 and 20.



Fig. 20—Light from the windows of well-lighted hangars is equally as effective as special exterior lighting

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Fig. 21—Night photo of Cleveland Municipal Airport lighted by a 24-kw. incandescent floodlight



Fig. 22—Night view of Newark Municipal Airport lighted by No. 1 Bank of six 3000-watt projectors

LIGHTING THE LANDING FIELD

The foregoing lighting facilities might all be classified more in the nature of navigation aids, that is, using light for direction, orientation, and warning indications. The lighting of the landing field itself is more strictly a general illumination problem and those planning airport lighting facilities should, as previously stated, anticipate future requirements, not in terms of minimum values, but in terms of safety, general utility, expediency of traffic operations, and good-will value of well-lighted surroundings. While the investment in lighting facilities is a considerable item in relation to the comparatively few plane movements today, yet the cost of the best system of lighting is small compared to its service in extending the use of the airport throughout 24 hours a day.

The present methods of lighting landing fields grew out of the early experience of the U. S. Army Air Corps in meeting the requirements for military operations. Army practice demanded flexibility and portable power apparatus using D. C. generator equipment in combination with a motor truck. For this service the 150-ampere arc with a modified type of BBT lighthouse lens, as shown in Fig. 23, was remarkably well adapted. The portable feature allowed the units to be moved about at will and located with respect to wind direction for favorable landing conditions.

With the precedent of army practice, the high intensity arc system was naturally adopted for the first commercial fields. Since these first installations, considerable study has been made of the lighting problem for commercial airport operations as contrasted

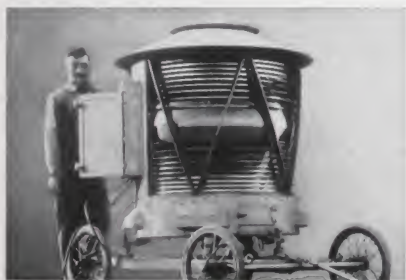


Fig. 23—Large Air Mail Type BBT Floodlight on carriage for portability

to army requirements. The expense incident to the servicing and attendant of the arc, the operation from fixed locations, and the general demand for more field illumination has led to the development of other field floodlighting equipments which have distinct advantages over the arc equipment.

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Principles Involved

The simplest specification for lighting landing fields, reduced to the fundamentals applied to other general lighting problems, can be stated in terms of lumens of light, or foot-candles, delivered per square foot of area. This is predicated on the generally accepted fact that the best illumination system for landing, taking off and general operations provides practically uniform distribution of light over the entire area. Certain illumination values from the standpoint of safety, obviously, can be set up, though these may be decidedly different from economical standards if one's conception of the problem embraces a broader view of the general economics and future of airport operation.

The requirement for uniformly distributed illumination carries with it certain related qualities which must be considered:

1. Upward light should be reduced to a minimum;
2. Glare from light sources should be eliminated as far as possible;
3. Harsh shadows should be avoided;
4. The color quality of the light should not distort normal color appearance of objects.

Limitations quite similar are imposed on the design of any interior lighting system and they have been overcome by the proper design and location of the lighting equipment. For example, in a store or office it is entirely feasible to supply all the light required from a single high wattage lamp but the lighting results might be intolerable because of glare, harsh shadows, and poor distribution. Accurate design data as regards spacing, mounting and utilization efficiencies for interior lighting systems are now well established.

If it were not for the necessity of keeping the landing area free of overhead obstructions a system of overhead lighting from ordinary industrial type reflectors would probably give the best lighting results. This being impractical, the only alternative is to locate the lighting equipment at the boundaries and, by proper design of equipment, project light to cover the area most effectively. The problem of lighting large areas of this sort has been met in other applications, such as lighting of stadiums, athletic fields,

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Fig. 15—Field floodlighting projectors are designed to illuminate a fan-shaped spread of light over the landing area; the true vertical perspective view of light distribution shows that the top of the beam is sharply cut off and the vertical dimension is limited to a 10-degree spread or less.

and railroad yards, by the use of batteries of floodlighting projectors mounted on buildings or high towers, directing a cross-spread of light over the desired area. Here, too, the lighting results can be computed with a fair degree of accuracy. Thus one large stadium is lighted by 180 projectors using 1500-watt lamps requiring 252 kilowatts. The lighted area comprises about 100,000 square feet.

In landing field lighting the same sort of treatment is applicable although complicated by the fact that to erect high towers on which to mount projectors would, in many cases, introduce obstruction hazards which are now regarded as distinctly undesirable. Already certain imaginative individuals have suggested the feasibility of grouping airport buildings in the center of the landing field to be reached by underground passageways. Such a trend in airport layout would also considerably use present ideas of practical lighting methods. To light a large area from projectors mounted close to the ground requires that the light be projected at only a slight angle with ground level. This results in an extremely high ratio of foot-candle values on the vertical as compared to the horizontal plane, and tends to create long, unnatural shadows.

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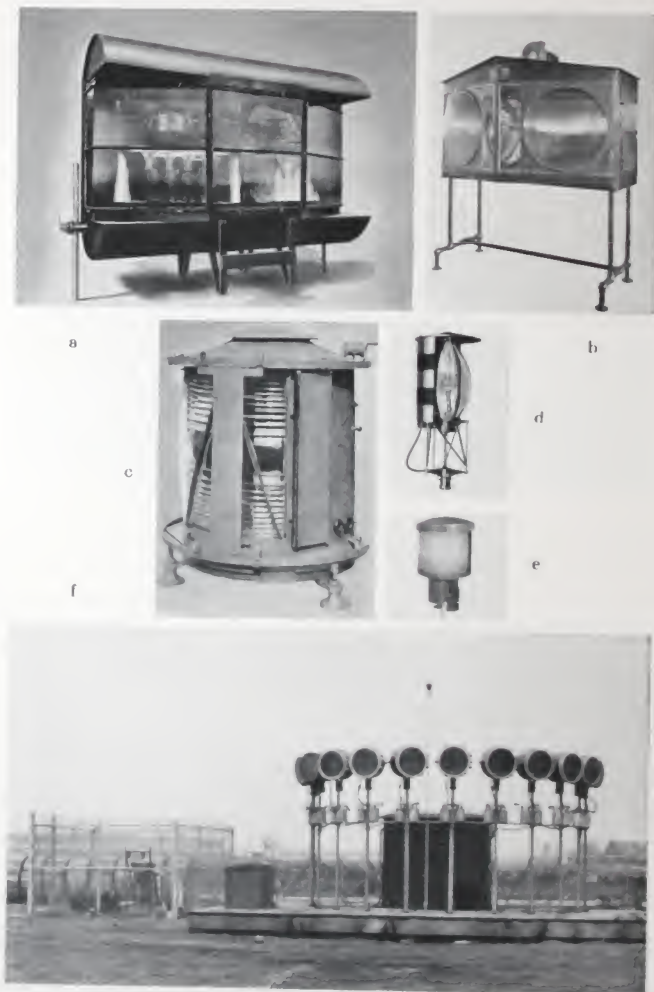


Fig. 25—Equipments especially designed for field floodlighting—(a) G. E. Type ALH, using eight 3000-watt or 16 1500-watt MAZDA lamps; (b) G. E. Twin, Type ALT, using two 10-kw. or two 5-kw. MAZDA lamps; (c) BBT using 150-amp. arc or one 10-kw. MAZDA lamp; (d) Crouse-Hinds Type AKP 1.5, or 5-kw. MAZDA lamp; (e) G. E. Type ALF using 1000-watt MAZDA lamp; (f) Westinghouse bank, lamped with 3-kw. or 1.5-kw. MAZDA lamps

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Trees, fences, buildings, and other vertical surfaces appear extremely well lighted even at a considerable distance away. This may give an observer on the ground a false impression as to the adequacy of the general field illumination as seen from a plane overhead.

Present Practice

Two major points have always been considered in lighting the landing field. The first is that the light must necessarily be projected out in such a fashion as to sweep the entire landing area in order that the area for night operations would be as large as the area suitable for landing purposes in the daytime. The second point has to do with the design and location of projectors to eliminate glare and stray light which would blind the pilot taking off or making a landing.

Two systems of field floodlighting, each possessing certain advantages and disadvantages, have been employed in deference to the two major points mentioned:

1. The "distributed" system comprises a number of 1000 or 1500-watt floodlights spaced at intervals of 200-300 feet around the boundaries of the field. This allows, perhaps, a more uniform distribution of light over the entire area, particularly where the terrain is uneven or slightly rolling, since each individual projector may be so adjusted and directed as to cover a particular section. The disadvantages from the standpoint of illumination is that the multiplicity of light sources introduces a large number of glare points.

2. The "concentrated" system comprises several batteries of relatively small individual projectors or, more commonly, one or more large units with one or more light sources built into a composite, high-powered projector. The uniformity of light distribution from the concentrated system is dependent upon mechanical and optical limitations of design. In general the ratio of minimum to maximum horizontal illumination over the field will be considerably greater than with the distributed system. However, the problem of glare is reduced, since precautions may be applied more readily to a single source than to a large number of sources; furthermore, no glare is experienced when the direction of flight is in the same general direction as the projected beam.

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Both of the preceding systems might be discussed in considerable detail, although the advantages and disadvantages of either system, as well as the initial and operating costs must be considered in their relations to specific conditions as encountered in lighting any given airport. However, to those who have given the problem most thought the ultimate solution seems to lie in the combination of the two systems.

Amount of Light Required

Any specific recommendations as regards the amount of light required for the landing field would be quite arbitrary. In interior lighting for stores, offices and factories, and in exterior lighting for streets and floodlighting, certain standards have been set up from time to time. Such standards serve merely as an index of practice; they are more in the nature of minimums. The more experienced the illuminating engineer, the less inclined he is to specify the upper limit in the amount of light that may be economically justified. Ten to twenty times as much light is being recommended and installed today as was accepted practice 15 years ago.

Fortunately, in the new problem of lighting for aviation, we can draw on our wealth of knowledge of light and vision grown out of our experience in other classes of lighting.

The airport rating regulations of the Department of Commerce specify an even distribution of light over the entire usable portion of the landing area with a minimum illumination of 0.15 foot-candles on the vertical plane. To the war-time pilot, who learned to set his plane down safely by the light of a gallon of gasoline burning on the ground, general illumination of the order of 0.15 foot-candles may seem relatively abundant. To meet this requirement, projector units of the order of 20,000 watts capacity are employed. However, on a landing field of average dimensions, say 2000 feet square, 4,000,000 square feet, the lighting result from this 20,000 watt projector is roughly equivalent to the lighting of a room 20 feet square by means of a single candle set on the floor in the corner.

This amount of light in a room seems little for ordinary moving about and modest, indeed, for an airport where plane movements at high speeds, and often under adverse weather conditions must be carried on with every precaution for safety of life and property.

Illumination Results and Calculations

A combination of circumstances has made it seem desirable to mount field floodlighting units only 10 feet or so above the ground, and to attempt to sweep the entire landing area with a flat fan of light. With such an acute angle of projection, the case of maximum candlepower must be aimed only the slightest amount below the horizontal plane in order to project light to the far boundaries of the field. Under these conditions of projection the lower half of the beam falls on the field, while the upper half is lost so far as lighting the ground is concerned. With a narrow vertical spread and a sharp cut-off this upper part of the beam produces in effect a layer of light above the field projected nearly parallel with the ground. Except when the atmosphere is extremely dense with dust or moisture particles, this upward light may produce a blanket of light sufficient to obscure the ground. In fact, some pilots have learned to gauge their height above the ground by the length of the beam. On the other hand, if more light can be directed toward the ground and if the landing surface is light in color, the surface brightness will be high enough to overcome the apparent ground haze and allow the ground to be seen through the haze. This would appear to dictate a higher mounting of projection and perhaps a modified beam pattern in order that the light might be directed more efficiently toward the ground.

With the present scheme of low mounting of field floodlighting equipment, the ratio between vertical and horizontal illumination is very marked. This is shown in Fig. 26 which illustrates some illumination measurements taken at 200 feet and at 2500 feet from a 24-kilowatt 180-degree aviation floodlight developing slightly over 2,000,000 maximum beam candlepower. It will be noted that at 2500 feet the vertical illumination is well over 3.15 foot-candles minimum required by the Department of Commerce, but the horizontal illumination is of the order of 0.0062 foot-candle or only about one-fiftieth of the vertical.

At 200 feet the vertical illumination was of the order of 25 foot-candles while the horizontal foot-candle fell to 3.37 foot-candles. The ground in the immediate vicinity of the projector appears fairly well lighted and favorable for landing with the beam, since the pilot has the advantage of absence of glare, relatively high ground illumination at the point where he grounds the wheels and

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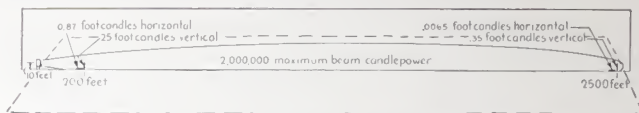


Fig. 26—Illumination readings on horizontal and vertical planes taken 3 feet above the ground for two locations on field, at zone of maximum projected candlepower.

has the further advantage of high vertical lighting on grass tufts, or weeds, that indicate the field conditions ahead.

On the other hand, if he is forced to approach from the far side of the field toward the unit, the horizontal illumination is almost negligible, (the reading of .0065 foot-candles is only about half what one could expect from full moonlight) so that the ground conditions are quite obscure; furthermore he cannot benefit by the vertical illumination since he is on the dark side of all such obstacles.

Shadows caused by irregularities in terrain or weeds become particularly objectionable, for they are apt to give the pilot a false impression of the condition of the landing area. Small knolls casting deep shadows cause the latter to appear as deep holes or valleys.

These facts almost conclusively point to the futility of trying to light an area as large as an airport landing field adequately with one high-powered projector or battery of projectors; nor is it any more expedient to provide a number of projectors strategically located unless powered to deliver adequate light volume comparable to the area to be lighted.

Provision should be made, for immediate installation or for future additions, of 200 kilowatts of electrical energy for floodlighting landing fields of average size. It is reasonable to anticipate requirements to this extent, not alone because maximum safety will be dependent on the use of more light, but equally for psychological reasons in that the well-lighted fields will go a long way to accelerate public confidence in the practicability of night flying operations.

Distribution of Light: Avoidance of Glare

The uniform distribution of light and the avoidance of glare are dependent upon both the design features of the lighting equipment and on the location of the equipment about the field.

Headlight projections for field floodlighting purposes are designed to produce a flat blanket of light over the entire landing area. The vertical beam spread is sharply limited to 2:1 to 10:1 type dimensions and the beam is so aimed that the top of the beam does not illuminate the horizontal thereby minimizing glare when a pilot lands or takes round the run. Because of the absolute necessity of avoiding glare as far as possible, the single high-powered source has been preferred to the system using many powerful sources distributed at many points around the field boundaries. When each single source was located with respect to prevailing wind direction, the pilot is free from glare the greater portion of the time since landings may be made over the tail end in the most direction in the projected beam.

This system, however, lacks the flexibility to meet all conditions as they arise. Early army practice and at many European airports at present, the desired flexibility is obtained by installing the powerful projection on a light column which is swivelled to various points on the field according to wind direction so that landings are always made over the tail and pilots need never fall into the beam. Such a scheme, while flexible in use, is cumbersome and costly in operation. Lighting engineers have for some time felt that the most flexible, most convenient, and most desirable system will require one, preferably two, high-powered units located on each side of the field. Such a system is illustrated in Fig. 27.

With such a system, so installed that each unit is controlled individually from a single control point, the prevailing wind direction would determine the particular units that would be lighted so that landing and taking off would always be made in the direction of projected light; subsequently, glare would cease to be a serious matter. Two, or three, or even four, units to the rear and right sides might be used simultaneously, thus requiring the amount of light as required for any occasion, or for various conditions of visibility. Furthermore, the use of several sources of light, for because of their location, produces a cross-direction of light, prevents

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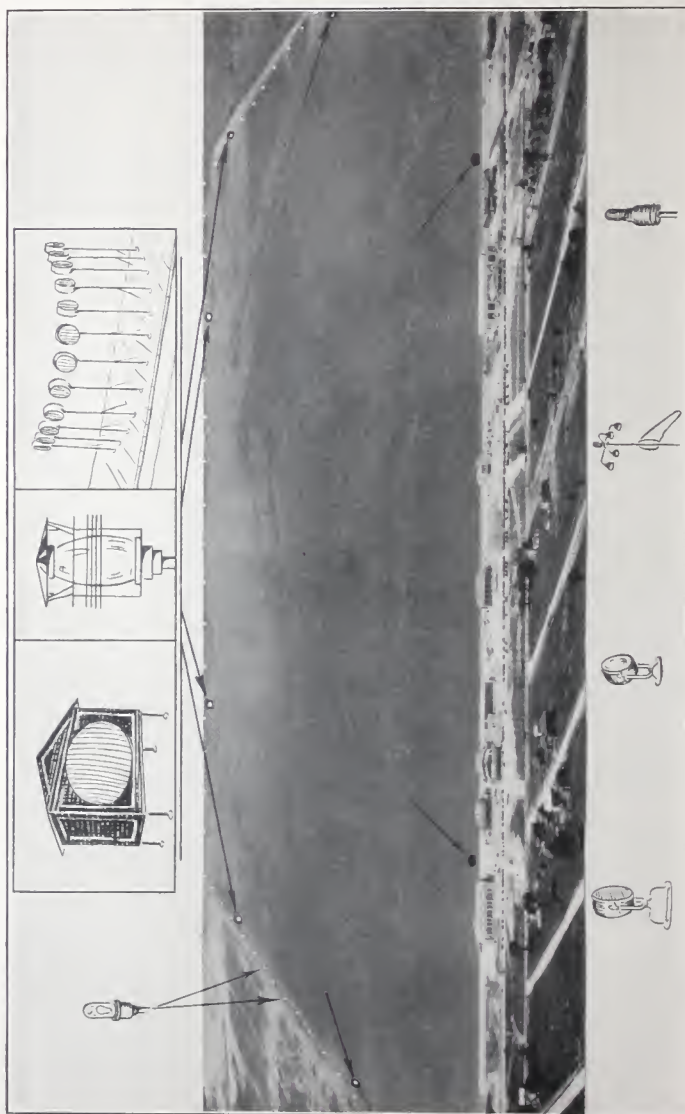


Fig. 27—View showing locations for field floodlighting equipments for adequate lighting and flexibility of control to insure proper distribution of light and avoidance of glare.

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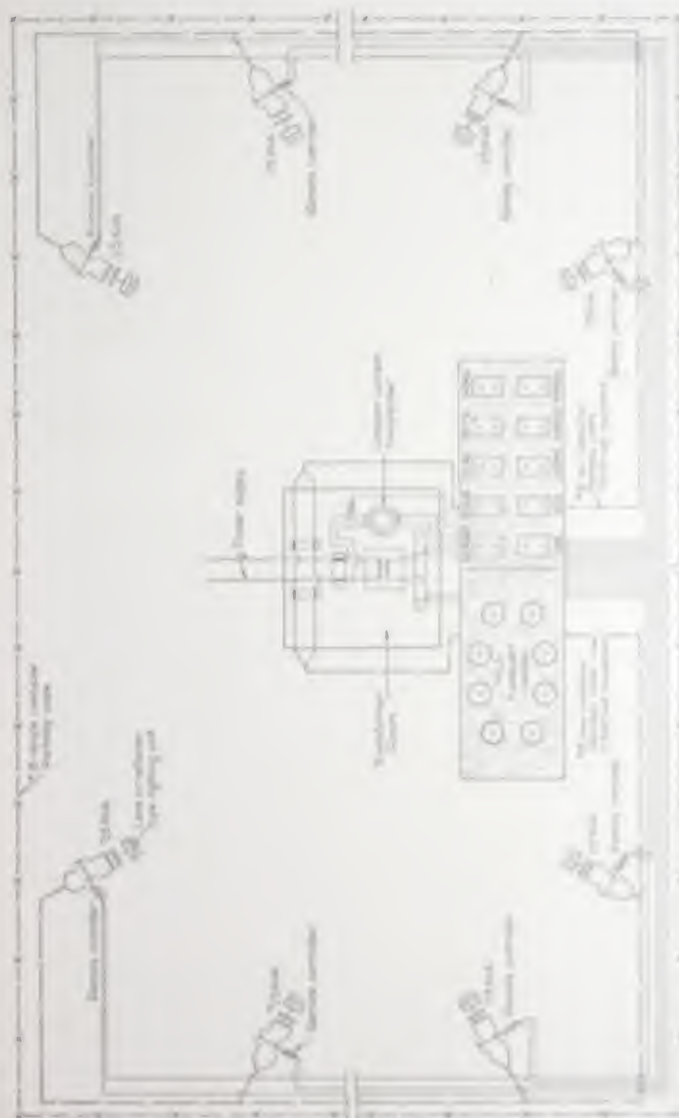


Fig. 24.—Wiring and electrical provisions for convenient control of all lighting equipment from a central point. Floodlights each with individual remote control.

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uniformity of distribution and eliminates harsh shadows cast by the plane itself, or caused by rolling or wavy terrain.

Systems of this sort, where they have been installed, have proved most satisfactory and deserve serious consideration on all airport projects.

The matter of cost has been a deterrent to the full provision for adequate lighting facilities. Naturally, municipal budgets are not particularly elastic. Initial expense incident to the establishment of an airport has in most cases limited the appropriations for lighting, this in spite of the fact that no one denies that the success and value of an airport depends to a large measure on its lighting facilities. It is natural that we may expect lower costs on equipment as the demand increases and greater sales volume is obtained. Already noticeable reductions in cost of airport lighting equipment have taken place. Furthermore, as time goes on it is reasonable to expect that the relative cost of airport operations will decrease with the increase in air traffic.

In reviewing airport lighting plans it will frequently be wise economy in the long run to develop fairly comprehensive plans initially and install additional equipment from time to time which fit in with the fully developed plan. Such a plan may involve a number of fundamentals which would otherwise require major changes in the electrical installation. For example, if provision is made for the installation of 8 high-powered floodlight projectors at the boundary of the field, which ultimately will require multiple distribution and transformer equipment at the several points about the field, some economy can possibly be shown by the use of the multiple system in the boundary lights, since in this case the length of run from distribution points is materially reduced. Furthermore, it is logical to expect that as new buildings and hangars are located about the field, it will be necessary to bring electric current to these points for general illumination of these buildings.

Reflection Characteristics of Field Surfacing Materials

It now appears that if airport sites are to be usable the year around—to eliminate boggy conditions following spring thaws and heavy rains, and to reduce the dust nuisance in dry weather,

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hard surfaced runways or specially treated surfaces must be provided. The reflection characteristics of the field surface are so dominantly important as far as lighting results are concerned that it would be unfortunate if the lighting efficiency and effectiveness are not considered along with the other factors of cost and durability which influence the choice of a certain material.

We see as a result of light which is reflected from the object to the eye. If the object is of good light reflection qualities, that is, one whose reflection factor is high, it will appear brighter and can be seen more distinctly than a dark-colored object of low reflection factor.

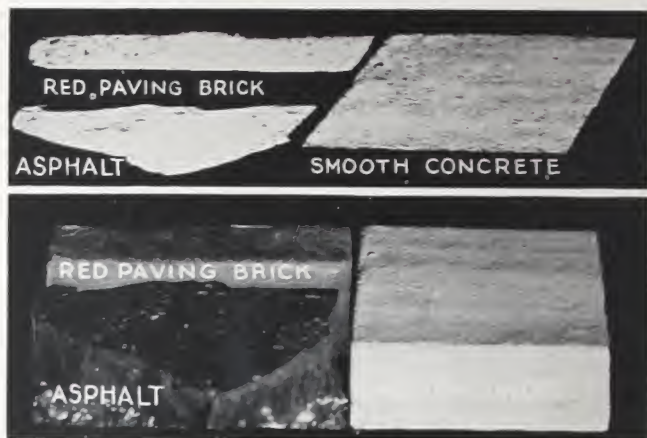
For example a surface having a reflection factor of 80 per cent (fresh whitewash) will appear 10 times as bright as a surface whose reflection factor is 8 per cent (cinders or asphalt). In other words, a given system of lighting would be 10 times as effective where white surfacing is provided in comparison to the use of dark-colored materials.

The following table shows the reflection characteristics of various field surfacing materials, which values show the relative efficiency from a lighting standpoint:

	SURFACE MATERIAL (Dry)	Approximate Reflection Factor
Semi-Hard	Crushed Stone	25
	Crushed Slag	20
	Gravel	20
	Cinders	5-10
Hard	Bituminous Macadam	
	Bituminous Concrete	
	Portland Cement	30
	Crushed Stone (Whitewashed)	75
	Asphalt (Tarvia)	5
Natural	Clay Soil	20
	Sandy Soil	10-12
	Black Soil	5-8

These data are not intended to affirm or deny the merits of various types of paving materials but rather to show how various surfaces differ in lighted appearance. It is strongly recommended that this factor be considered along with other facts in the choice of materials and that provision be made to maintain a high reflection value of all surfaces by the periodic application of whitewash or paint.

LOOKING AHEAD IN AVIATION LIGHTING



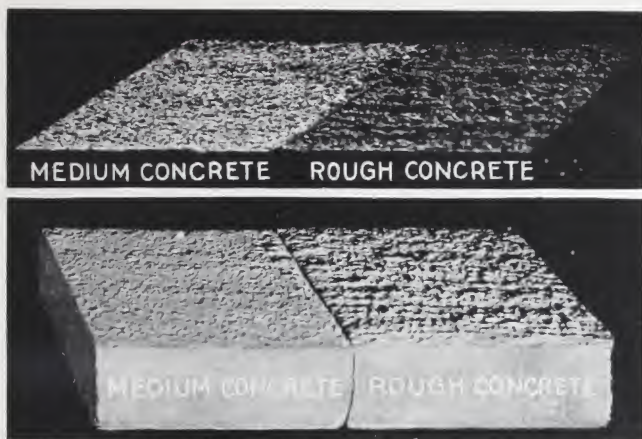
Upper View—Appearance of surface when landing toward light source.
Lower View—Normal appearance when landing with projected beam.



Fig. 29 — Upper Photos — Materials used for field and runway paving are shown as they appear under conditions of specular reflection and under normal diffuse reflection. It will be noted that smooth dark or oily surfaces produce glaring reflections when viewed toward the light source.

Lower Photos — The reflection characteristics of these same surfaces are shown when dry and when wet. The amount of reflected light in each case depends upon the color of the surface, while the direction of the reflected light depends on the smoothness of the surface, which in effect may change considerably when wet.

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Upper View—Appearance of surfaces when landing toward light source.
Lower View—Normal appearance when landing with projected beam.



Fig. 30—These photos show two additional samples of concrete surfaces of rougher finish and are comparable with the examples shown in Fig. 29.

In addition to the reflection factor of surfacing materials, the matter of surface finish is of considerable importance. Since we see by the light that is reflected from an object to the eye, and since the angle of incident light from low mounted projectors is so acute, a roughened diffusing surface is to be preferred to a smooth, oily surface. The former scatters the light so to be visible from all directions while the latter reflects the bulk of the light in one direction. These characteristics are shown in the accompanying photographs of various types of surfaces.

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It will be seen that the reflection characteristics differ widely, depending on whether the surface is wet or dry.

If a complete system of lighting is provided so that landings and take-offs are always made with the beam, the matter of glare reflected from the wet surfaces is obviated. Because of the high vertical component of illumination, there would appear to be considerable advantage in seeing the ground if a number of small vertical baffles or light targets were installed at different points about the field. Such targets could be made of rubber not unlike the rubber STOP signs oftentimes found at street intersections which present no obstacle but which would seem to be quite effective as light targets to pick up and reflect back 30 to 50 times the amount of light that would come from horizontal surfaces.

AIRWAY AND AIRPORT MARKING

The Department of Commerce urge that all cities and towns be air-marked by means of painted and night-lighted signs on roofs of prominent buildings, factories, tanks, railroad stations and the like. Such markings, identifying the town and giving airport directions, are of decided importance to air navigation. At night, when all natural landmarks, highways, rivers and railroads are obscured, lighted markings are of major importance.

One of the basic requirements of the Department of Commerce in granting an airport rating is that every airport shall be marked by lettering the name of the city or town on the ground or upon at least one airport building, and visible from an altitude of 2000 feet.

Painted signs should consist of simple block letters in chrome yellow on a dull black background. A minimum letter height of 6 feet is specified with recommendations for 10, 15, or even 20-foot letters if space permits. For any given letter height, the other proportions should be about as follows:*

Minimum letter width.....	$\frac{3}{8}$ of the height
Width of Stroke.....	$\frac{1}{2}$ of the height
Minimum space between letters.....	$\frac{1}{4}$ of the height
Approximate length of the sign—Height of letter x Number of letters	

* Complete instructions on lettering and symbols for airway signs are to be found in the Report of the Airway Marking Committee published by the Department of Commerce.

LOOKING AHEAD IN AVIATION LIGHTING

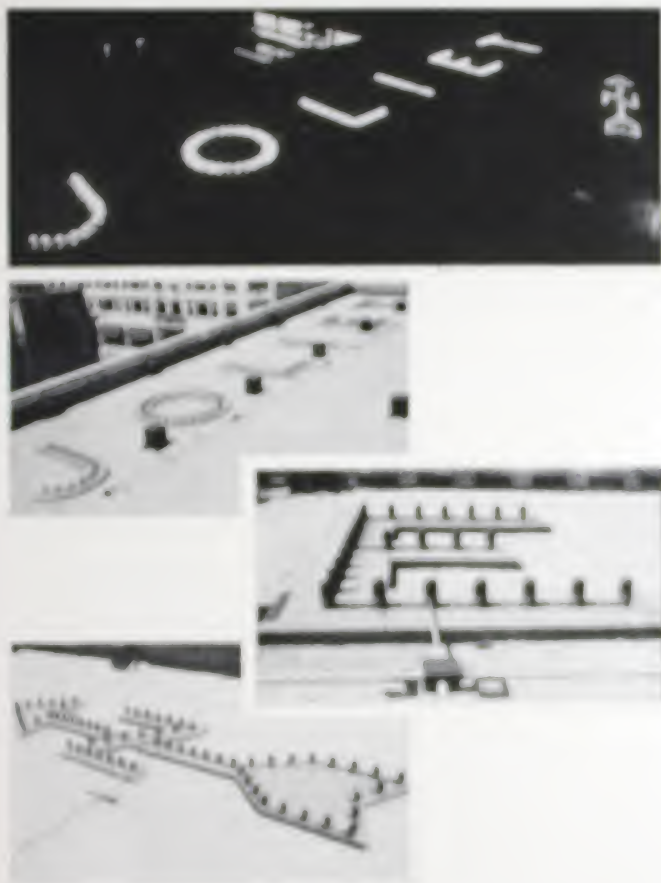


FIG. 11

Top—Aviation road signs at night

Below—Views illustrating construction details. The letter outlines are concrete slabs held in a grooved track. Light metal covers with sockets 12 inches apart follow the letter outlines to form a lamp sign. Glass pipes with weather proof fittings protect the lamp and socket joints. The sign was 18" to 24" long in the letters and arrow, and under favorable atmospheric conditions should be legible at a distance of over 1000 feet.

LOOKING AHEAD IN AVIATION LIGHTING

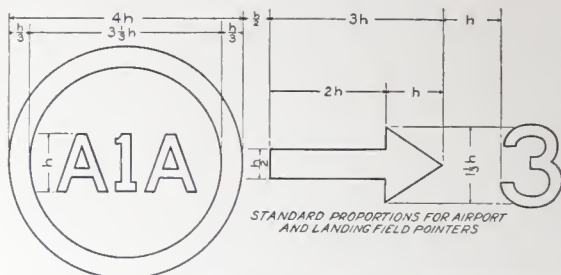


Fig. 32—All airway marking should conform to certain standards set up by the Department of Commerce.

Lighted signs of the character shown on the preceding page are unquestionably the most effective for all aviation markings. Not only is the exposed lamp type of sign quite as economical to install and maintain, but because of its greater brightness it attracts more attention, is legible at greater distances, and is more effective in heavy weather when needed most.

Painted letter signs may be lighted by means of ordinary floodlights or by angle type reflectors so arranged to illuminate the sign uniformly. The equipment must be mounted above the roof on poles or conduit pipe, which is somewhat detractive in appearance. The lower brightness of signs lighted by reflected light makes them ineffective at great distances or in hazy weather. Furthermore, their night-time effectiveness is dependent upon how well the painted surface is maintained.

The exposed-lamp type of sign always has the advantage of great brightness and therefore attracts attention to a greater degree than reflected light signs. The over-night failure of a few lamps does not seriously impair the effectiveness of the sign. A further advantage of the exposed-lamp sign over the painted sign is that it is more effective at night, especially during the winter months, even though the painted background may be obscured by dirt or snow.

In this type of sign the lamps should be located along the center line of the strokes of the letters. An exposed-lamp sign is not dependent upon the background for its night-time effectiveness and, if it were not for the requirement of daytime service, no painted letter background would even be necessary.

LOOKING AHEAD IN AVIATION LIGHTING

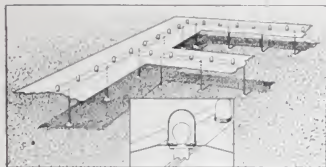


Fig. 33—From the standpoint of maintenance during winter months, in localities where snow is likely to impair continuous effectiveness, a sign of this type is of considerable advantage. The letters, formed of wood or cut out of metal, are mounted a foot or so above the roof and are lighted by a row of lamps along the center of the letter strokes.

An exposed-lamp sign can be constructed very inexpensively simply by following the painted letter strokes with lengths of conduit containing sockets a foot apart. Much of the cost of an ordinary electric sign is in the steel framework construction necessary to support the sign vertically against extreme wind pressure. Flat on a roof, however, only the skeleton of conduit is necessary. This conduit can be fastened to the roof at intervals with strap iron. Where this is impractical the conduit can be strapped to narrow wood or metal stringers and the whole framework superimposed on the painted sign and bolted down. The conduit, stringers, and sockets would, of course, be painted chrome yellow so as to be an integral part of the letter stroke when seen in the daytime.

The same principle applies to signs made up of letters cut out of wood or metal instead of being painted directly on the roof. The Joliet sign illustrates a very fine construction of an exposed-lamp sign. The concrete slab letters offer a solution to the difficulty of painting a sign on a gravel roof, and at the same time makes the job of anchoring the conduit fairly simple. Fig. 33 suggests the construction of a sign with letters formed of galvanized iron or porcelain-enameled steel. The slightly sloping sides tend to shed dust and dirt, and being set up above the roof, the sign is effective even with a considerable amount of drifted snow.

The lamp sockets should be spaced 12 inches apart along the letter strokes. To prevent corrosion and serious deterioration of socket parts, it is recommended that the lamp and socket be protected by a clear or light yellow glass hood. These hoods and holders are readily available and provide a fairly dust-tight and water-tight housing for the lamp and socket. Rubber washers which fit snugly around the neck of the lamps and cover the top of the socket are available and can be used in place of the water-tight glass hoods.

LOOKING AHEAD IN AVIATION LIGHTING

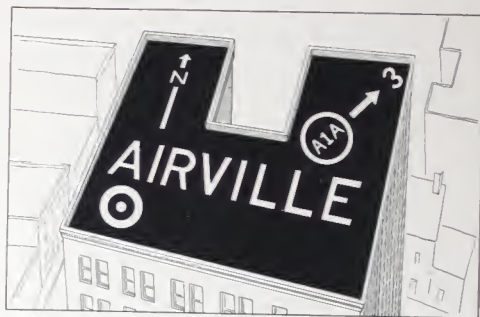


Fig. 34—Typical aviation roof sign showing various designations as recommended by the Department of Commerce

The choice of the size of lamp to be used is governed by the two factors of attracting power and legibility. In general, 10- and 15-watt lamps will be satisfactory in dark districts. The use of larger lamps will produce a brighter sign which will command greater attention, and this factor is of importance in locations adjacent to brightly-lighted streets or near advertising signs.

The matter of proper maintenance cannot be over-emphasized. Provision should be made for cleaning and repainting airway signs as often as required and frequent inspection should be made of lighting equipment for lamp replacements and cleaning. Any sign designed to serve as a navigation aid should be so maintained that the pilot may safely rely on it.

At the larger airports where there are quite a number of hangar buildings, lighted signs on the roofs of each hangar would provide a ready means of hangar identification. Such signs could be constructed with characteristic lettering and colored lamp combinations to produce attractive signs of distinct advertising value, aside from their use as orientation markers for incoming pilots.

One important use of lamp signs is suggested by the need, even now, for some method of control of air traffic at busy times when several ships are in the air over an airport. It seems likely that some system of lighted signals—letter or color combinations, lighted symbols, or numbers prominently displayed at a convenient point may be an effective means of transmitting instructions to incoming pilots.

AIRPORT BUILDING LIGHTING



Fig. 35—At night the life of an airport is in its lights. Crowned by colorful markers, and aglow with light, well-lighted airport buildings reflect the enterprise and progress of the aviation industry. The building in the foreground houses the waiting room, offices, pilots quarters and through the open hangar door one sees many eager steeds of the air being groomed for the daily schedule on passenger and mail routes.

It is, of course, impracticable in this bulletin to give in detail, recommendations for the lighting of all the various buildings that will be found at the average large airport. The problem of lighting the general offices—weather bureau station, pilots' quarters, waiting rooms, restaurants, etc., is no different than that encountered elsewhere. Suffice to say, all such buildings should be well lighted according to the latest standards of practice.

The hangar building should be provided with a good system of general illumination with a symmetrical arrangement of units similar to the layout shown in Fig. 36. Because of the high mounting of units, usually 15 to 25 feet, a relatively large spacing between



Fig. 36—An installation of 200-watt vapor-proof units spaced 15 feet apart. Four supplementary floodlights are mounted on each of the side walls.

LOOKING AHEAD IN AVIATION LIGHTING



Fig. 37—This large hangar is lighted by fifty-six 200-watt prismatic glass units mounted flush with the ceiling and spaced on 14 x 18 foot centers.

units may be employed and still obtain fairly uniform distribution of light when the hangar is vacant. It is recommended, however, that the spacing between units not exceed 20 feet in order to avoid heavy shadows and dark areas caused by the wings of planes which intercept or block off light from one or more widely spaced units.

The RLM and other common types of industrial reflectors are most widely used for hangar illumination, although more strict interpretations of the Underwriters Code require that vapor proof fixtures be installed in this type of building. A hangar lighting system should deliver at least 10 foot-candles in order that repairs, servicing and maintenance may be done without inconvenience. Circuits should be arranged from the standpoint of economy of operation during the periods when less light is needed. As an indication of the wattage necessary for the recommended standard of illumination in the standard type hangar building, two watts per square foot should be installed with provision in the wiring capacity to install at least 3 watts per square foot in the future. These allowances are comparable with present day recommendations for the rougher grades of industrial work.

AIRPLANE LIGHTING EQUIPMENT

The lighting facilities required on the airplane itself for night flying are not greatly different from those required for automobiles and motor coaches, and most of the present equipment used is an adaptation from automotive practice. The problem is more complicated, however, in the economic limitations of weight and space for battery and generator equipment—thus restricting the energy available for lighting purposes over any considerable period of time.

The source of energy for lighting consists of a standard 12-16 volt battery, for continuous use of instrument and navigation lights and with sufficient capacity for a 20 or 30 minute use of high powered headlights for normal and emergency landing purposes. Such battery equipment is generally charged at terminal points although some transport lines, anticipating night passenger traffic are equipping their planes with direct driven generator, and battery systems.

All planes in night flying service, in addition to the lighting of the instrument board must be equipped with wing tip and tail lights in suitable units and so mounted as to be visible from practically any angle. The typical units shown in Fig. 38 consists of a receptacle inside of a thin stream-lined pyralin shell, inserted in the wing tips and rudder, or mounted on short stem brackets. Red on the left wing, green on the right, and white at the rear are the standard indications of these navigation or running lights.



Fig. 38—Rear navigation light mounted on tail-fin of plane

LOOKING AHEAD IN AVIATION LIGHTING



Built-in type of Landing Light



Landing Light mounted under the wing



Landing Light of disappearing type in down position



Landing Light pulled up into wing when not used

Fig. 39—Various methods of installing airplane landing lights on wings; similar equipments are sometimes installed on the fusilage above the landing gear.

Landing lights similar to the types illustrated in Fig. 39 were developed early for the service of the airmail. The units consist of a parabolic reflector using a 12-volt, 35 ampere concentrated filament lamp. When externally mounted the housing is streamlined; other types are either built into the wing tips, or are mounted and hinged so that they can be drawn up into the wing when not in use, thereby lessening wind resistance.

While units of this general type have been practicable and serviceable, still it is evident that improvements can be made in the optical performance of the equipment and in its flexibility and control. Before any degree of standardization can take place, a study must be made of the requirements for various classes of service to determine what sort of beam characteristics are most suitable and to what extent the lights should be controllable by the pilot, in short, to learn, as the experience of the industry broadens, just what results are most desirable. This study is now under way.

LOOKING AHEAD IN AVIATION LIGHTING



Fig. 40—Lighting of the interior of a large passenger plane. The provision for lighting and the arrangement of units is splendid, though the capacity of the system forces economy in the use of electrical energy. It is interesting to note that a total of 28 lamps comprises the complete installation on this plane.

The lighting of cabin planes in passenger transport service is analogous to motor coach lighting requirements. The interior should present a well-lighted appearance, the light should be diffused, and sufficient light should be provided for comfortable reading. Enclosed dome lights provide a soft quality of general illumination and, in combination with individual side wall brackets, can be made to supply a fair amount of illumination for reading purposes. The lamping will depend upon the capacity of the energy supply system. The lighting of the cabin shown in Fig. 40 is provided by dome lights supplemented by individual wall brackets, lamped with 3 c.p. frosted bulb lamps. The illumination for reading is only slightly more than one-half foot-candle. If capacity is available shaded, 15 c.p., or even larger, lamps should be used. This would give more desirable results, from the standpoint of reducing glare as well as to increase the illumination to a more satisfactory level.

APPENDIX

Table I is a summary of the MAZDA lamps regularly available for various applications in aviation service. Essential technical data are included for the information of equipment manufacturers and for reference of airport and aircraft operators.

Table I—MAZDA Lamps for Aviation Service

Application	Type of MAZDA Lamp Used
Airway Beacons	<u>Revolving Beacon</u> 1000-watt, 115-volt, T-20 bulb, concentrated filament lamp. Over-all length $9\frac{1}{8}$ in. Light center length $4\frac{3}{4}$ in. Rated average life 500 hours. Mogul screw base.
	<u>On Course Projectors</u> 500-watt, 115-volt, T-20 bulb lamp. Over-all length $9\frac{3}{8}$ in. Light center length $4\frac{3}{4}$ in. Rated average life 800 hours. Mogul screw base.
	500-watt, 115-volt, G-40 bulb, floodlight lamp. Over-all length $7\frac{1}{16}$ in. Light center length $4\frac{1}{4}$ in. Rated average life 800 hours. Mogul screw base.
Airport Beacons	Same as for revolving airway beacon; in addition, the 1000-watt, 30-volt, T-20 bulb lamp is used to a considerable extent.
Ceiling Light	<u>Projector</u> 500-watt, 115-volt, T-20 bulb, concentrated filament lamp. Over-all length $5\frac{1}{2}$ in. Light center length 3 in. Rated average life 50 hours. Mogul screw base.
	The 250 and 400-watt, 115-volt, G-30 bulb lamps and the 1000-watt, 115-volt, G-40 bulb lamp, designed for spotlight service—200 hours life—are well adapted to this service.
Boundary, Approach, and Obstruction Lights	<u>Series Circuits</u> Clear Globes—600 lumen, 6.6 amp. (avg. watts, 43.3) S-24½ bulb lamp. Over-all length $7\frac{1}{8}$ in. Light center length $5\frac{3}{8}$ in. Rated average life 1350 hours. Mogul screw base.
	Red or Green Globes—1000 lumen (avg. watts, 64.1) lamps; other data same as above.
	<u>Multiple Circuits</u> Clear Globes—50-watt, (540 lumens) 115-volt A-21 inside frosted bulb. Over-all length $4\frac{1}{8}$ in. Light center length $3\frac{3}{8}$ in. Rated average life 1000 hours. Medium base. Red or Green Globes—100-watt (1360 lumens) 115-volt A-23 inside frosted bulb. Over-all length $6\frac{1}{8}$ in. Light center length $4\frac{3}{8}$ in. Average life 1000 hours. Medium base.

APPENDIX

Table I—MAZDA Lamps for Aviation Service (Continued)

Application	Type of MAZDA Lamp Used
Field Floodlights	10-K. W. Lamp (260,000 lumens) 10,000-watt, 115-volt, G-80 bulb, concentrated filament lamp. Over-all length 20 in. Light center length 12 in. Skirted prong base. Rated average life 100 hours. Used in G.E. Twin and BBT Type M-8-D floodlighting units
	5-K.W. Lamp (130,000 lumens) 5000-watt, 115-volt, G-64 bulb, concentrated filament lamp. Over-all length 15½ in. Light center length 9 in. Prong base. Rated average life 100 hours. Used in G. E. Twin, BBT Type H-3-D, Crouse-Hinds Type AKP-24 equipments.
	3-K. W. Lamp (78,000 lumens) 3000-watt, 32-volt, GT-38 bulb, concentrated filament lamp. Over-all length 17 in. Light center length 7 in. Prong base. Rated average life 100 hours. Used in G.E. Type ALH, Crouse-Hinds Type DCE 24, Westinghouse, Pyle-National, and similar equipments.
	1.5-K. W. Lamp (34,500 lumens) 1500-watt, 32-volt, T-24 bulb, concentrated filament lamp. Over-all length 13¾ in. Light center length 5¼ in. Prong base. Rated average life 100 hours. Used in G. E. Type ALH, Crouse-Hinds Type AKP-14 Westinghouse, Pyle-National, and similar equipments.
	These applications use the ordinary types of Mazda lamps in sizes ranging from 10 to 1500 watts.
Miscellaneous— Floodlighting, Signs and Interior Lighting	
Aircraft Lighting (12-16 Volt Battery and Generator Systems)	Landing 12 volts, 35 amperes, G-25 bulb. Mogul screw base—over-all length 5¼ in., light center length 3 in. Prefocus base—over-all length 5¾ in., light center length 1½ in. For horizontal or base-down burning. Rated average life 50 hours.
	Navigation MAZDA No. 1142, 12-16 volts, 1.33 amperes, 21 c. p., S-10 bulb, D. C. bayonet base. Over-all length 2¾ in. Light center length 1¼ in. Rated average life 300 hours.
	Instrument MAZDA No. 68, 12-16 volt, 0.28 amperes, 3 c. p., G-6 bulb, D. C. bayonet base. Over-all length 1⅞ in. Light center length ¾ in. Rated average life 200 hours.
	General In addition to the two preceding lamps, there is available MAZDA No. 94, 12-16 volt, 1.02 amperes, 15 c. p., S-8 bulb lamp; also, MAZDA No. 1144, 12-16 volt, 1.61 amperes, 32 c. p., S-10 bulb lamp, for general interior lighting of cabin planes.



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